Economy Topic Team: Hydrogen *Station Costs*

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Introduction

- Motivation:
  - Put a price tag on the H2Hwy Network for different scenarios
  - Determine economical network configurations
- Questions:
  - How many stations?
  - What kind (e.g. electrolysis vs. reformation)?
  - How big (e.g. 10 vs. 100 kg/day?)
  - What are the benefits of Distributed Generation?
- Team Members
    - 30+ volunteers from public and private sector

Organization

1. Intro:
   – purpose of talk, goals
2. Station Cost Model
   – Methodology
   – Stations Choices & Rationale
   – Assumptions
   – Model Validation
3. Results:
   – Scenarios for Success
   – Sensitivity Analysis
4. Energy Stations (covered by Tiax)
5. Conclusions

Methodology

GOAL 1: Obtain realistic near-term station costs

GOAL 2: Identify important factors that affect station cost

- Cost Validation
  - Data collected from industry for equipment, station construction, and operating costs
  - Scaled for size and expected 2010 production volume
- Assumption Validation
  - Vetted with Economics Team, outside sources
  - Compared against assumptions in other reports
    - (e.g. NAS, Tiax, GM WTW)
- Model Validation
  - Undergoing review within Team
  - Forming Peer Review Committee

Stations Analyzed

Type of Station	Design Capacity (kg H_2/day)	Average Fuel Demand (kg H_2/day)	Average Cars Refueled per day
Mobile Refueler	10	1	0.5
On-site Production (SMR and Electrolysis)	30, 100, 1000	3, 10, 100	1, 3, 33
Delivered Liquid Hydrogen	1,000	100	33
Average Gasoline Station	-	3,000 gal/day	375 conventional cars/day

Note: Assumes avg. H2 demand of 0.66 kg/car/day (3 kg/fill) (based on 50 mpg, 12000 miles/yr), and 8 gallons gasoline per fill on average.

Capacity Factor = 10% (average consumption / rated production capacity).

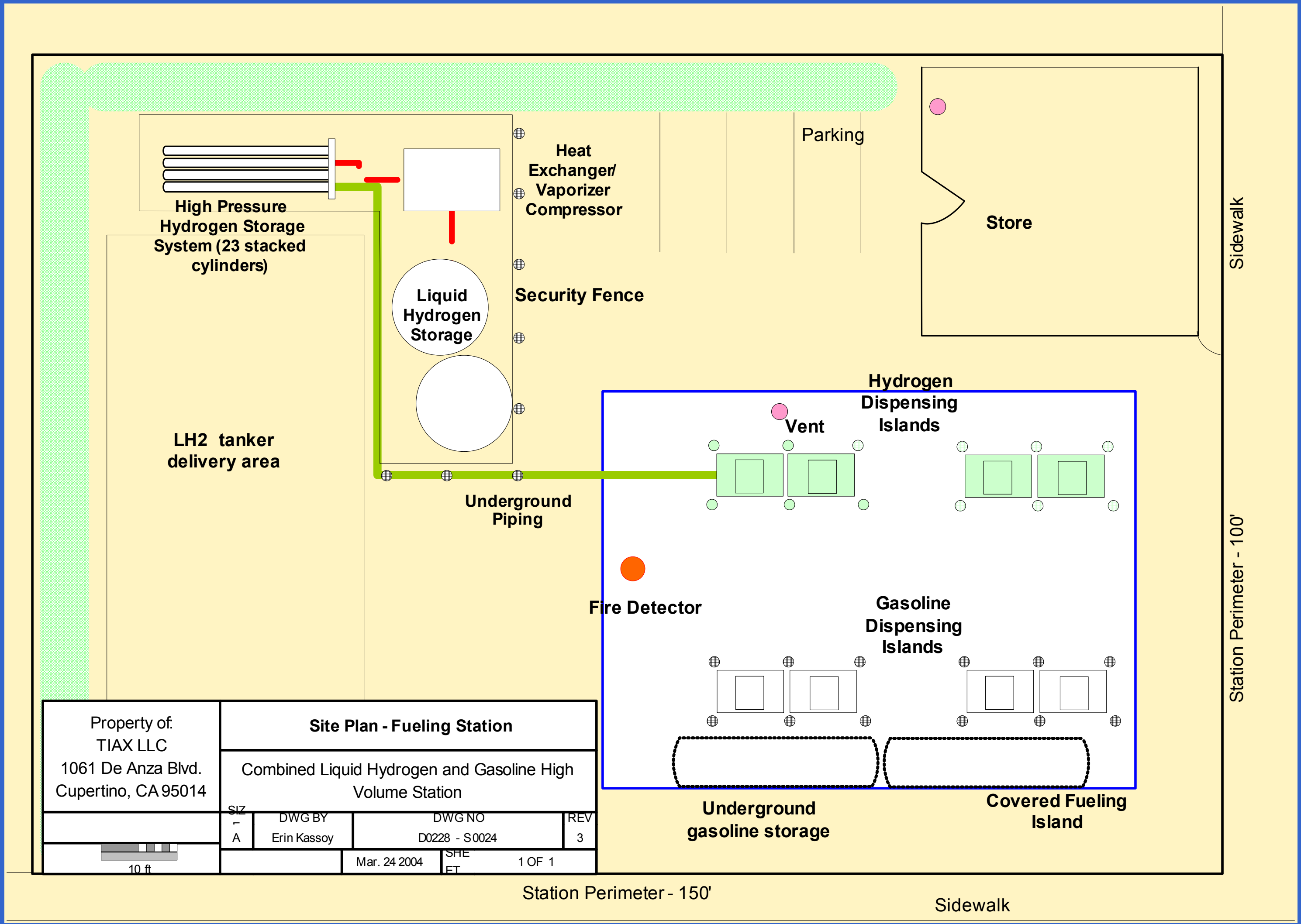
For Liquid delivery and mobile station, rated capacity based on assumed daily fueling window.

Design Assumptions (1)

Station Type	Key Technology	Additional Components
Mobile Refueler	Integrated Refueler Trailer	Cascade storage/dispensing
Natural Gas Reformer	Steam Methane Reformer, Pressure Swing Absorption	Reciprocating-piston compressor, cascade storage/dispensing
Electrolyser	Alkaline Electrolyser	
Delivered LH_2 Tanker Truck	Cryogenic Storage Tank, 6,250 Cryo-pump	evaporator + cascade storage dispensing

- Small and large H_2 stations are integrated into existing gasoline stations with 8 dispensers total
  - Small station = 1 cH_2 dispenser,   Large station = 3 cH_2 dispensers

Site Plan - LH2 Station Example



Note: Assumes 10% capacity factor and avg. H_2 demand of 0.65 kg/car/day (3-5 kg/fill) (based on 50 mpg, 12000 miles/yr), and 8 gallons gasoline per fill on average.

Design Assumptions (2)

- 6,250 psi dispensing compressed gaseous hydrogen
  - 5,000 psi on-board vehicle storage
- Storage and dispenser requirements based on rated station capacity
  - 2 daily peaks
  - 40% of total daily throughput in 3-hours

Economic Assumptions (1)

- Divide station operating labor between hydrogen / gasoline / non-fuel sales (1/8 or 3/8)
- Rent cost assumed for landscape and hardscape
  - Based on site plan
- Equipment costs based on industry costs and 2x today's production volumes
- Capital Cost amortized over 15 years with 10% return on investment
  - based on 15 year plant life
- Commercial utility rates

Economic Assumptions (2)

- Energy Prices based on review of several projections/forecasts (ISE Research)
  - Electricity
    - 9.7 cents/kWh California Energy Commission
    - 12.4 cents/kWh Chevron Texaco
    - 4 cents/kWh City of San Francisco, 12.4 cents/kWh
  - Natural Gas
    - 6.68 $/MMBtu Depart of Energy EIA
    - 5.93 $/MMBtu Wall Street Journal

Model Validation

- Assumptions compared to existing hydrogen reports:
  - Authur D. Little, GM, SFA Pacific, National Academy of Science
- Verifying assumptions with industry (e.g. electrolysis efficiency) revealed some reports too optimistic.

Parameter	Study	On-site NG Reformation	Electrolysis
Total Electric Consumption (kWh/kg)	***H2Hwy 2010***	***3.0***	***60***
	Lasher/ADL	3.41	53.45
	GM/LBST	2.16	53.84
	Simbeck/SFA Pacific	2.19	54.8
Natural Gas Consumption (J/J)	***H2Hwy 2010***	***1.35***	-
	Lasher/ADL	1.32	-
	Simbeck/SFA Pacific	1.43	-

H2Hwy Network Assumptions

– 10% station capacity factor, 5000 vehicles served

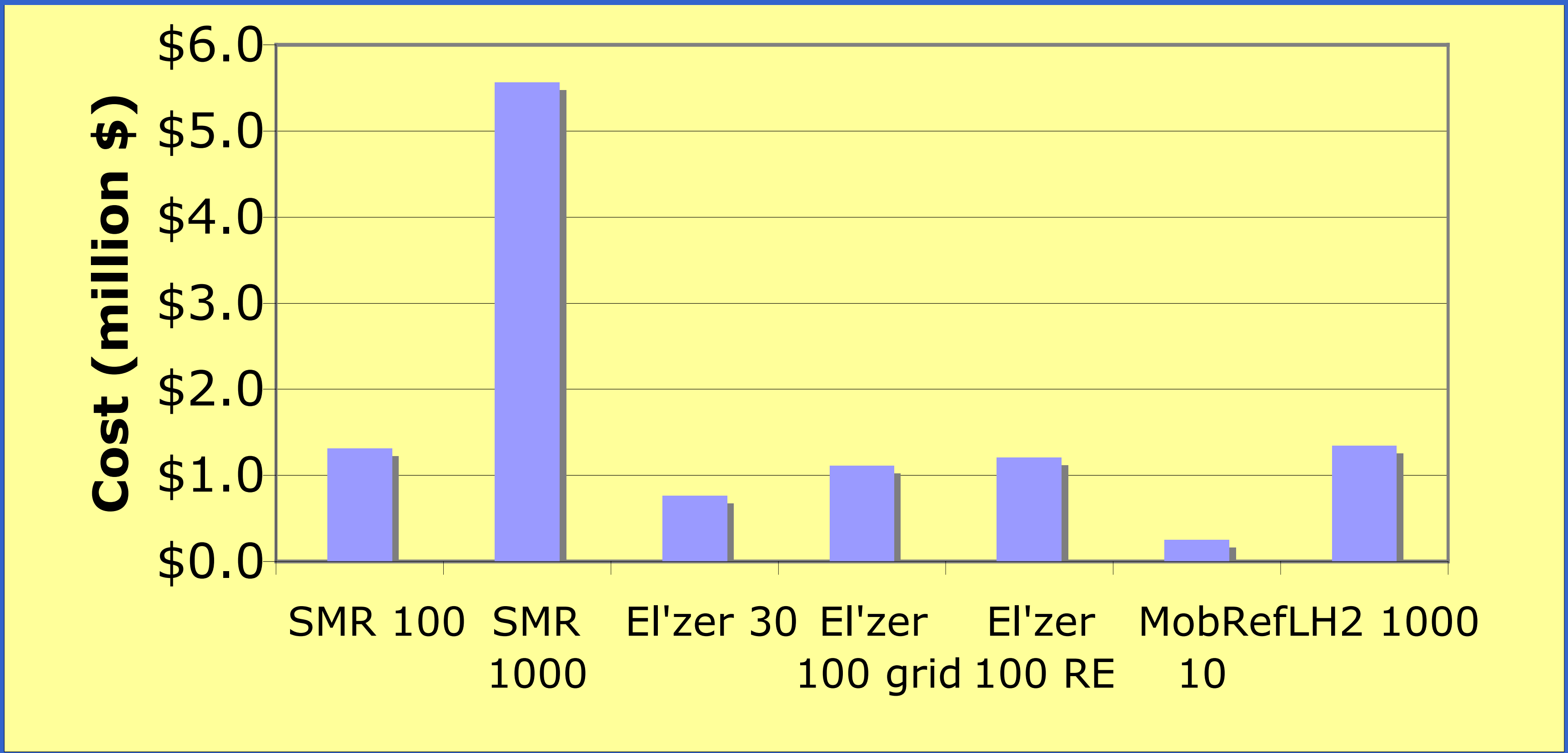
Station Type	**%**	**# of Stations**	**Cost (MM$/ Station**
1. Steam Methane Reformer, 100	8%	19	$1.32
2. Steam Methane Reformer, 1000	4%	10	$5.57
3. Electrolyzer, grid 30	15%	36	$0.76
4. Electrolyzer, grid 100	4%	10	$1.11
5. Electrolyzer, renewable energy 100	15%	36	$1.21
6. Mobile Refueler 10	38%	92	$0.25
7. Delivered LH2 1000	5%	12	$1.34
8. Energy Stations and Specialty Stations	11%	27	$1.58
Total	100%	**242**	

H2Hwy Cost: Baseline Scenario

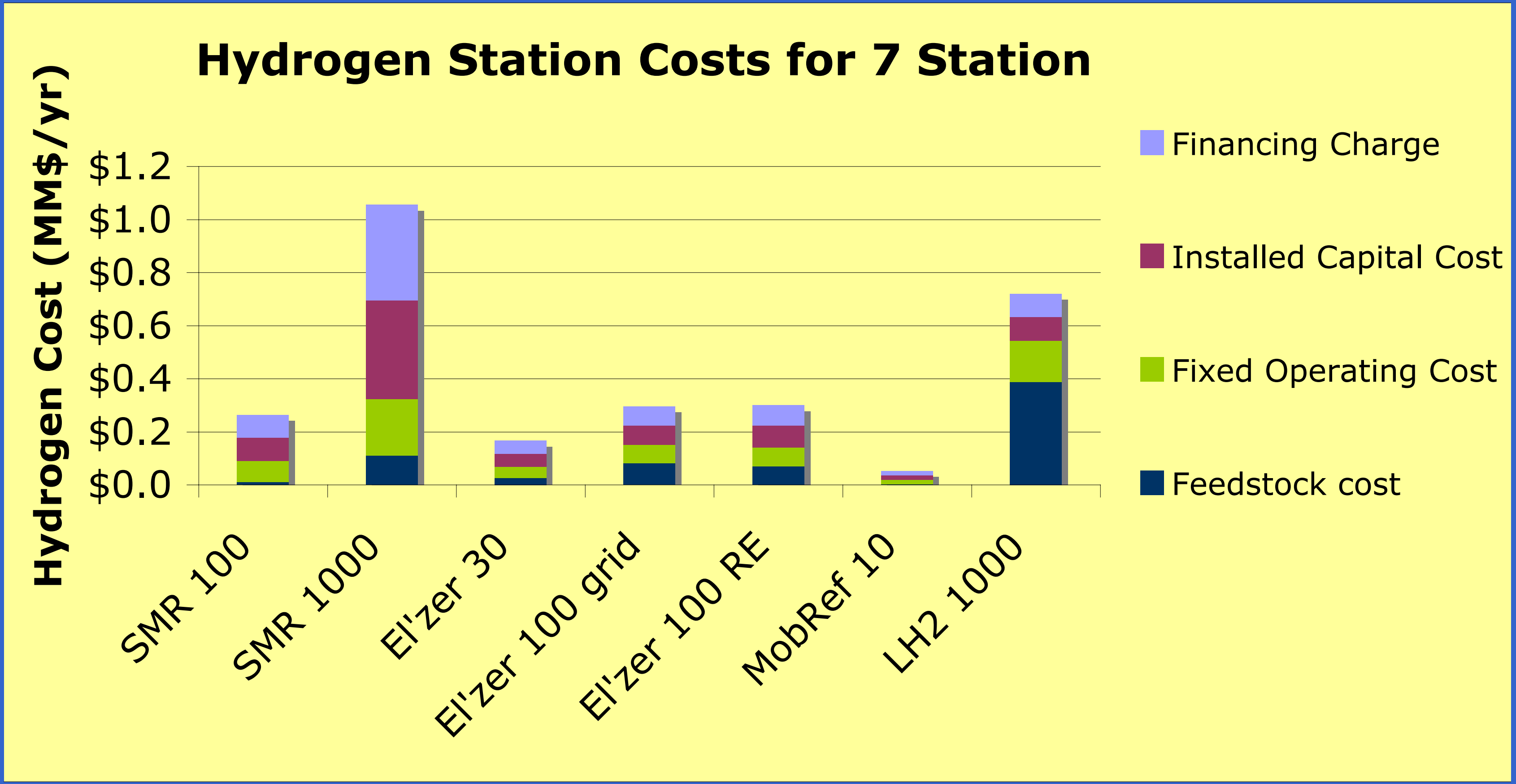
242 Stations to serve 5000 vehicles…

- Total Installed Capital Cost = **$244 million**
  - – Equipment Costs
  - – Non-Capital Installation Costs
    - Permitting, Site prep, Engineering/Design, etc.
- Total Annual Cost = **$52 million/yr**
  - – Includes amortized capital cost (above) and annual operating cost
    - Feedstock, maintenance, rent, labor

Installed Station Capital Costs: 2010 Retail Scenario



Annual Station Costs: 2010 Retail Scenario



Scenarios for Success

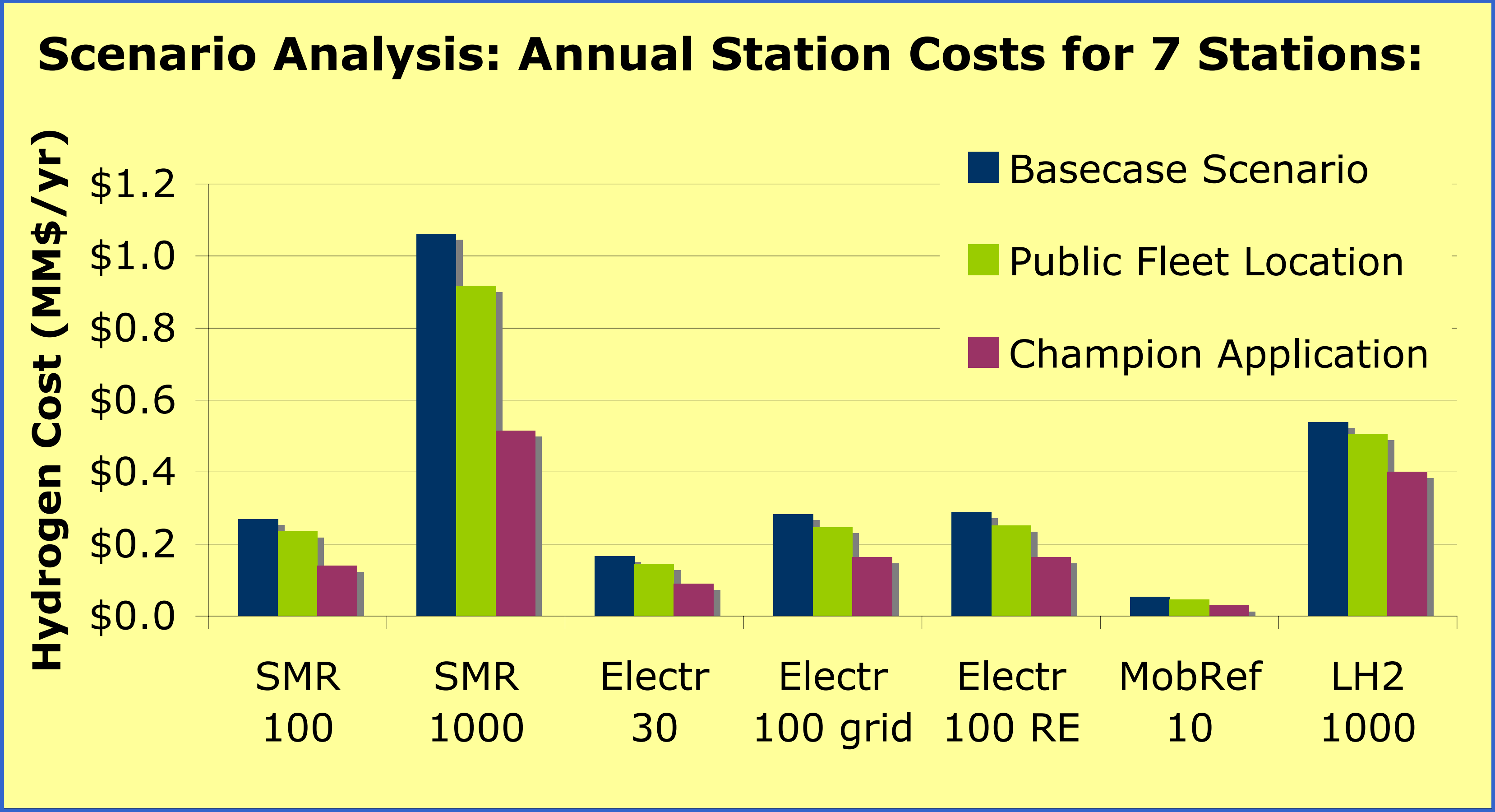
- Scenario 1: Baseline
  - Retail hydrogen station (similar to commercial gasoline)
  - 2010 production volumes
- Scenario 2: Public Fleet Location
  - Higher throughput, capacity factor
  - Lower utility rates though incentives & industrial classification
- Scenario 3: Champion Applications
  - Leverage public-private partnerships, 0% financing
  - Higher production volumes
  - Strong local authority cooperation
  - Co-locate with DG app or industrial hydrogen user

Assumptions Under 3 Scenarios

Assumption	Baseline Scenario	Public Fleet Location Scenario	Champion Application Scenario
Natural Gas ($/MMBtu)	7	5	5
Electricity Cost ($/kWh)	0.1	0.06	0.05
Capacity Factor	10%	10%	10%
Return on Investment (%)	10%	10%	0%
Production Volume Increase (from today)	2x	2x	5x
Real Estate Cost ($/ft^2/month)	$0.50	$0.25	$0
Installation Cost Reduction (%)	10%	20%	40%
% of Labor for Fuel Sale	50%	20%	0%
Contingency (%)	10%	10%	5%

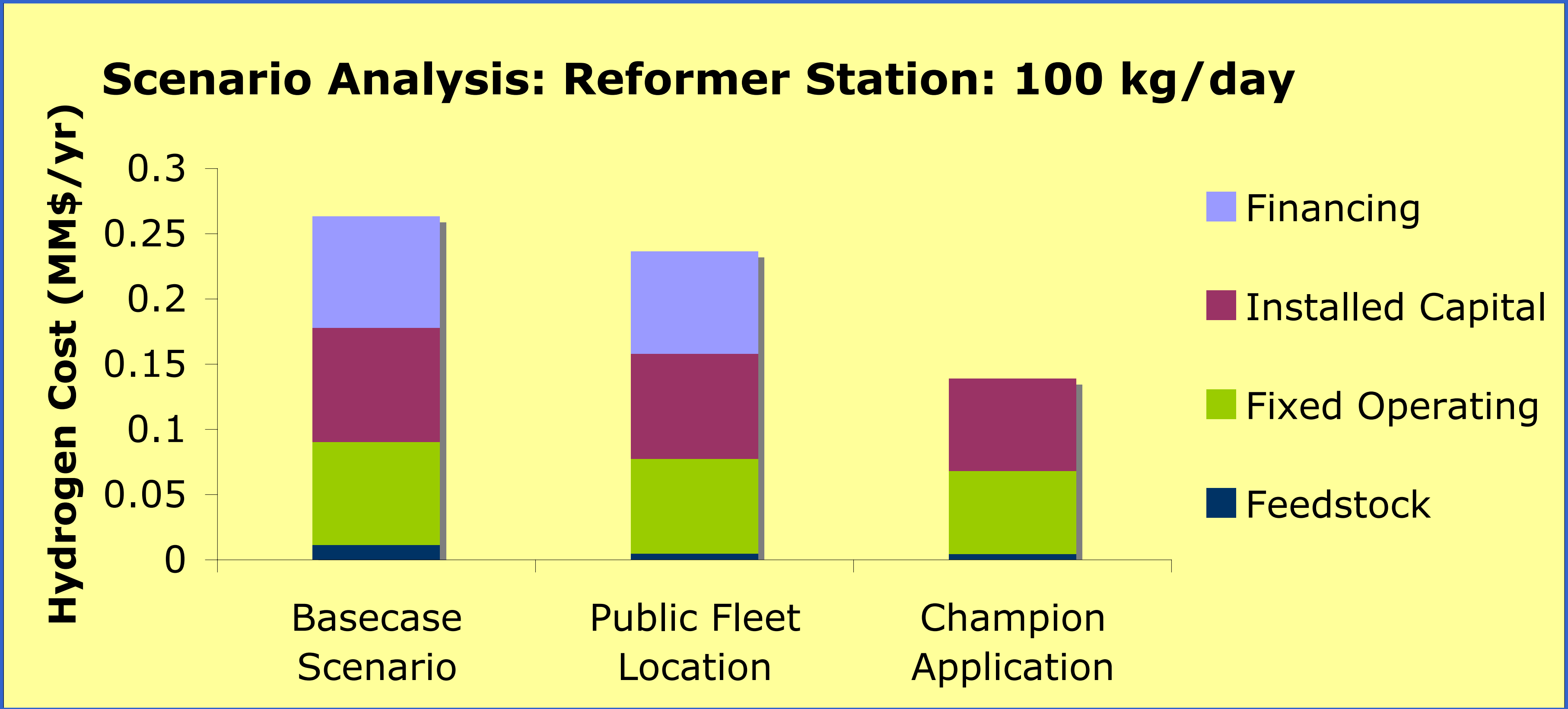
Note: Capacity factor is held constant due to it's misleading effect on annual station cost. It should increase with Scenario 2 and 3.

Scenarios for Success:

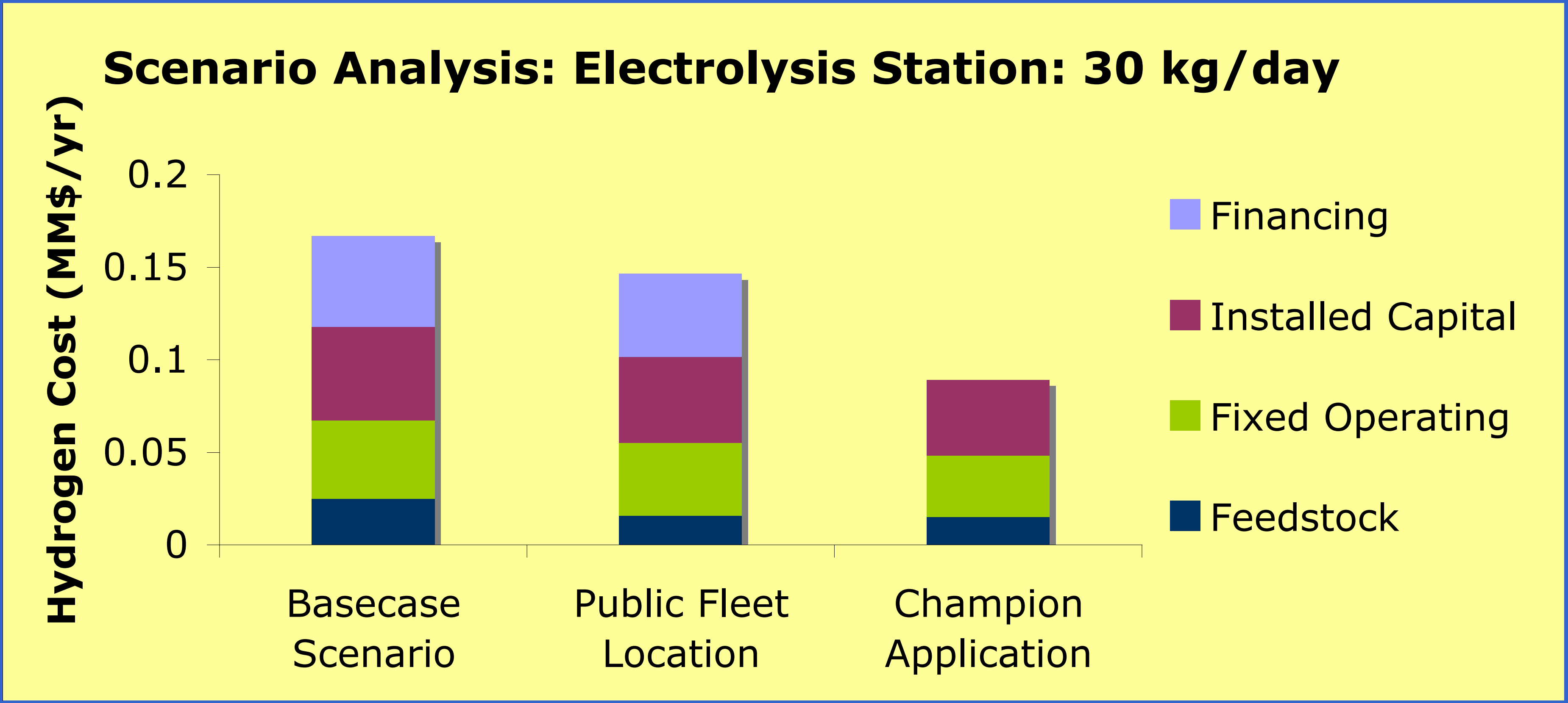


California Hydrogen Highways
www.hydrogenhighway.ca.gov

Scenarios for Success: Case 1



Scenarios for Success: Case 2



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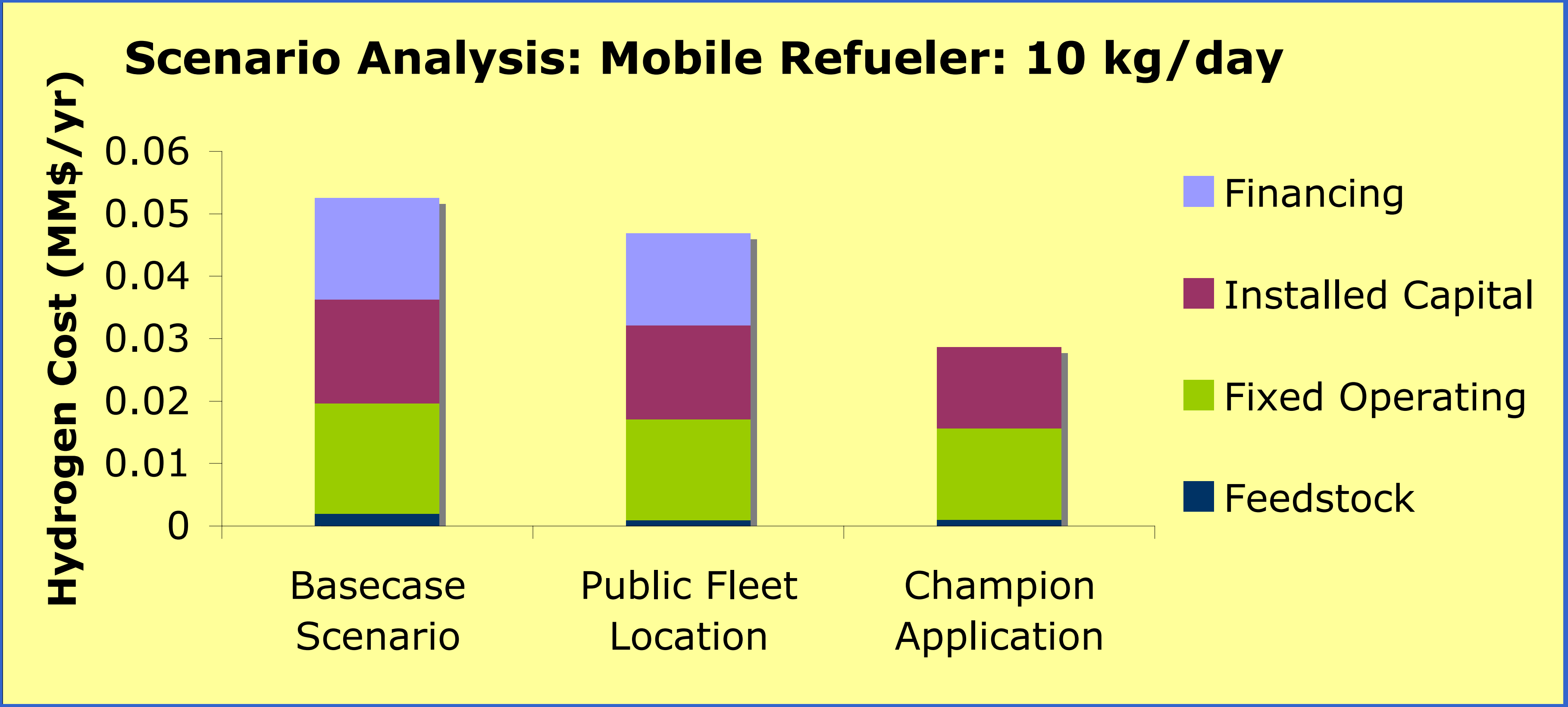
Scenarios for Success: Case 3

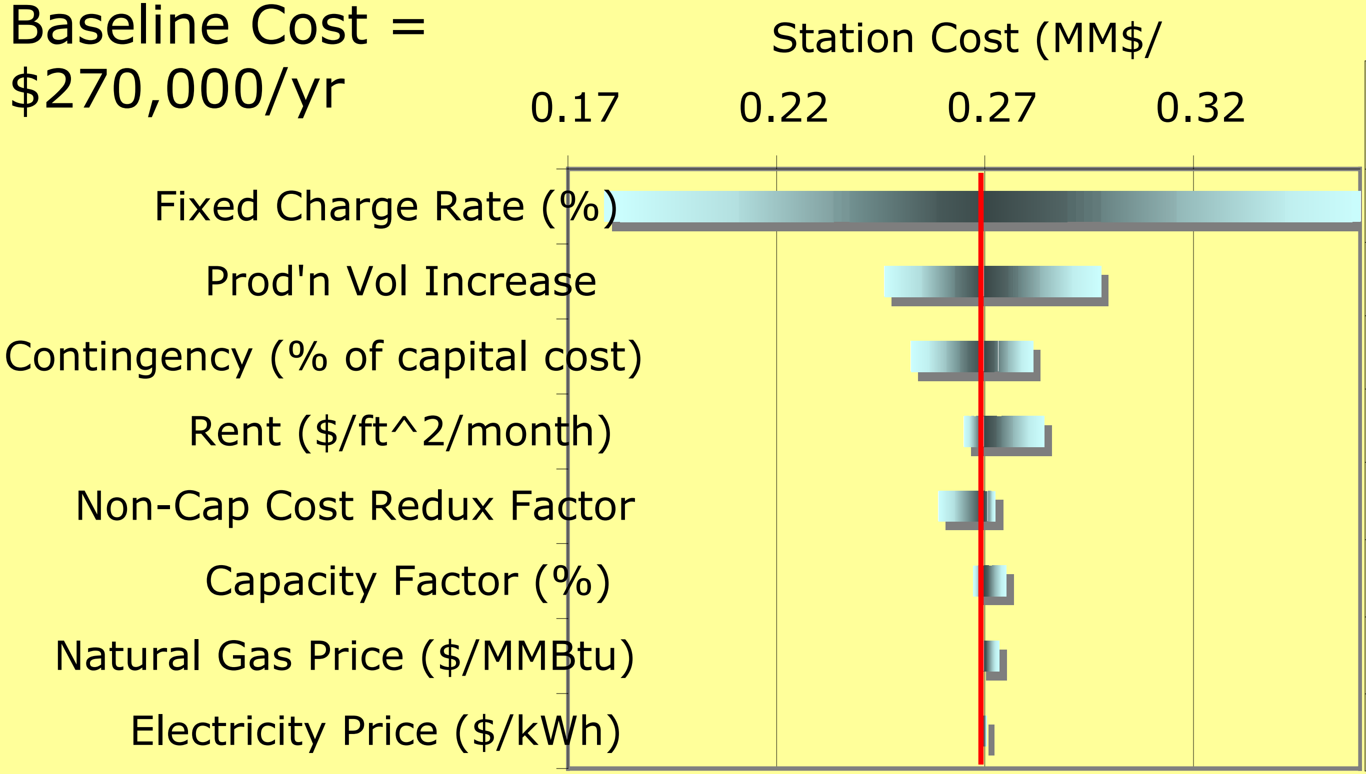


Sensitivity Analysis

	Basecase	Bright	Bleak
Natural Gas Price ($/MMBtu)	7	5	10
Electricity Price ($/kWh)	0.1	0.06	0.13
Capacity Factor (%)	70%	99%	40%
Fixed Charge Rate (%)	13%	7%	20%
Real Estate Cost ($/ft^2/month)	1.5	1	2
Contingency (% of TIC)	10%	5%	15%
Prod'n Vol increase	Double	Current	quadruple
Non-Cap Cost Reduction Factor	10%	0.0%	20.0%

Sensitivity Analysis: SMR 100

Baseline Cost = $270,000/yr

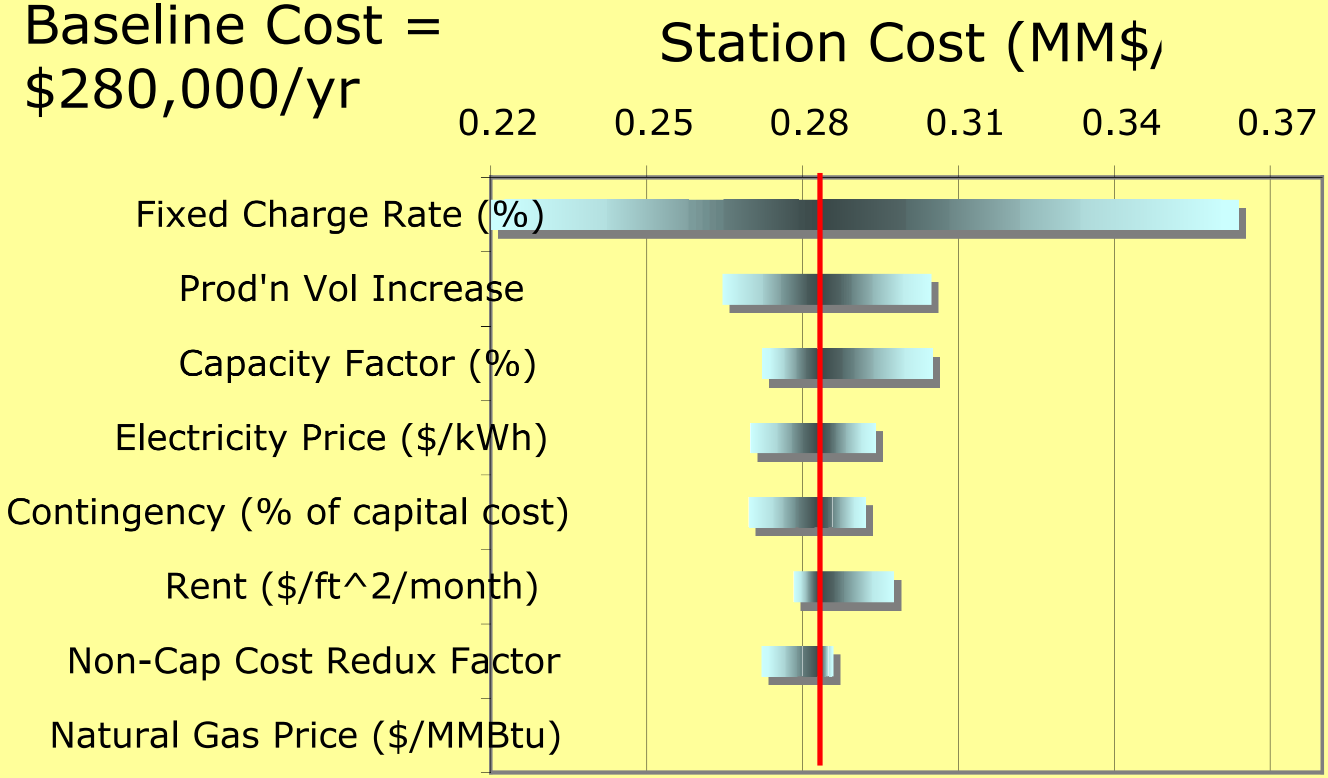


Base-line	Bright	Bleak
13%	7%	20%
2x	5x	1x
20%	5%	30%
0.5	0	2
10%	5%	30%
10%	30%	5%
7	5	13
$0.10	0.04	0.15

Note: Station cost rises with increasing capacity factor due to added operating costs.

Sensitivity Analysis: Electr’sis 100

Baseline Cost = $280,000/yr

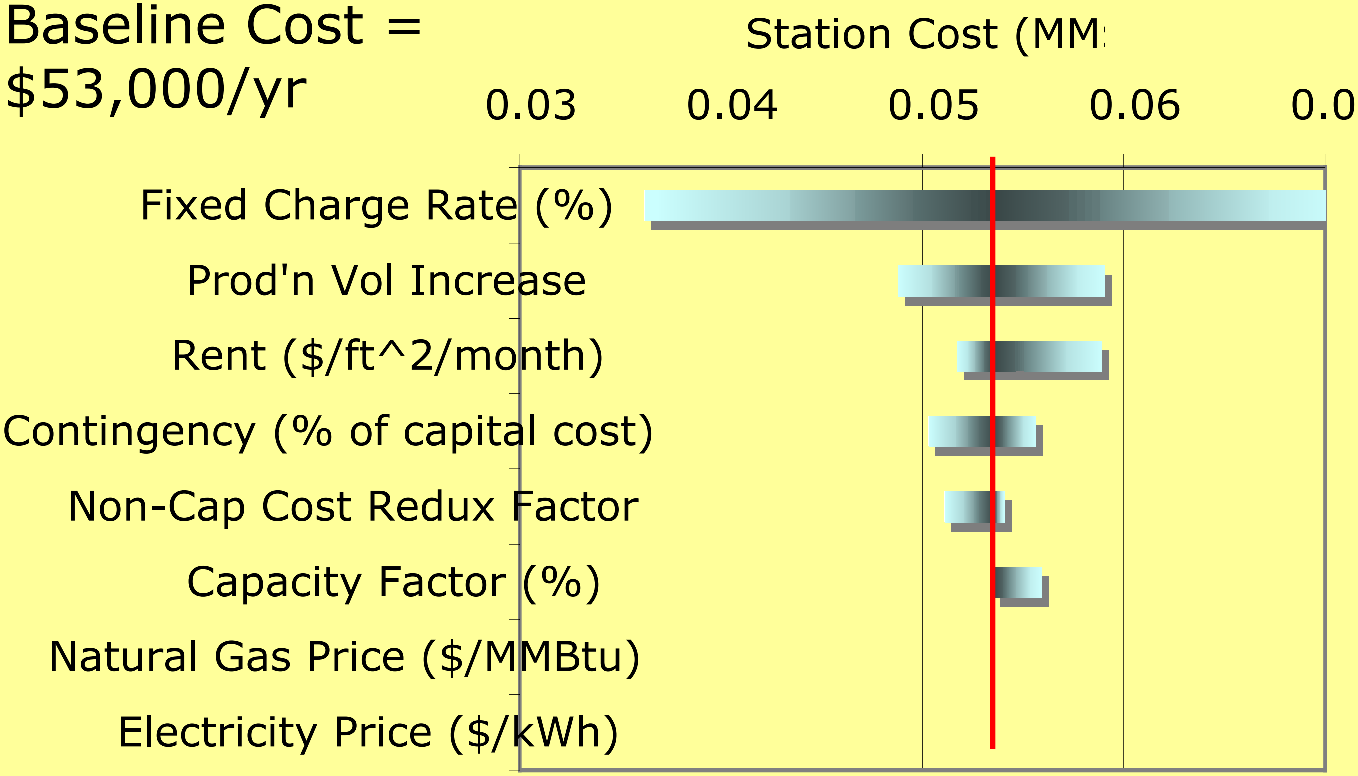


Base-line	Bright	Bleak
13%	7%	20%
2x	5x	1x
10%	5%	30%
$0.10	0.04	0.15
20%	5%	30%
0.5	0	2
10%	30%	5%
7	5	13

Note: Station cost rises with increasing capacity factor due to added operating costs.

Sensitivity Analysis: MobRef 10

Baseline Cost =
$53,000/yr



Base-line	Bright	Bleak
13%	7%	20%
2x	5x	1x
0.5	0	2
20%	5%	30%
10%	30%	5%
20%	5%	30%
7	5	13
$0.10	0.04	0.15

Note: Station cost rises with increasing capacity factor due to added operating costs.

Conclusions

1. Choosing "Champion Applications" can reduce station cost up to ~50%
2. Station cost very sensitive to:
   - Production Volume increases
   - "0% Financing"
   - Contingency cost reduction
3. Low expected capacity factors in near term lead to lower annual station costs though higher hydrogen cost

Acknowledgments

- UC Davis Institute of Transportation Studies
- Tiax, Stuart, Air Products, Chevron Texaco, Fuel Cell Energy, ISE Research, GM, Praxair, Proton Energy, Ztek, FTI, Shell, BOC, BP, Dynetek, H2Gen, Hydrogenics,

- REFERENCES:

Unnasch, S, Kassoy, E. and Powars, C (Feb, 2004), “Requirements for Combining Natural Gas and Hydrogen Fueling”, Consultant report for the California Energy Comission, Prepared by Tiax

Questions??